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AFRRI TECHNICAL REPORT

LINAC Facility at Armed Forces Radiobiology Research Institute

M. T. Gee

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DEFENSE NUCLEAR AGENCY
ARMED FORCES RADIOBIOLOGY RESEARCH INSTITUTE
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Research was conducted according to the principles enunciated in the "Guide for the Care and Use of Laboratory Animals," prepared by the Institute of Laboratory Animal Resources, National Research Council.

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The Armed Forces Radiobiology Research Institute LINAC is a traveling microwave type high-energy linear electron accelerator, which accelerates electrons to sufficient energies and in sufficient quantities to provide radiation fields of interest for radiobiological, radiochemical, and materials/component research. It provides radiation researchers with a source of high-energy electron or high-energy bremsstrahlung (X ray) radiation. This report gives details on the LINAC's design, operation, and capabilities.

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GENERAL DESCRIPTION

The Armed Forces Radiobiology Research Institute (AFRRI) LINAC is a traveling microwave type high-energy linear electron accelerator, which accelerates electrons to sufficient energies and in sufficient quantities (see Table 1) to provide radiation fields of interest for radiobiological, radiochemical, and materials/component research. The accelerator was designed by Varian Associates (Palo Alto, California). It was assembled at AFRRI starting in 1965, and the

Table 1. Performance Characteristics of AFRRI LINAC

MODE A'				
Electron energy:	20 MeV_{max}	18 MeV	13 MeV_{min}	
Beam current:	300 mA	600 mA	1.2 A	
Electrons: Maximum average dose rate			at .1 m without H_2O scatterer:	1 Mrad/pulse
			at 1 m without H_2O scatterer:	10 Krad/pulse
			at 5 m without H_2O scatterer:	10 rad/pulse
Bremsstrahlung:			at 1 m without H_2O scatterer:	5 R/pulse
Pulse repetition rate: 60 pulses/sec				
MODE A				
Electron energy:	20 MeV	18 MeV	13 MeV	
Beam current:	1.1 A	1.7 A	3.25 A	
Electrons: Maximum average dose rate			at .1 m without H_2O scatterer:	6 Mrad/pulse
			at 1 m without H_2O scatterer:	60 Krad/pulse
			at 5 m without H_2O scatterer:	60 rad/pulse
Bremsstrahlung:			at 1 m without H_2O scatterer:	15 R/pulse
MODE B				
Electron energy:	50 MeV	40 MeV	30 MeV	
Beam current:	250 mA	750 mA	1.2 A	
Electrons: Maximum average dose rate			at .1 m w/o H_2O scatterer:	1.5×10^6 rad/pulse
Neutrons: Peak instantaneous number			at .1 m w/o H_2O scatterer:	8×10^{15} n/sec
Bremsstrahlung:			at 1 m w/o H_2O scatterer:	30 R/pulse

first beam was available to investigators in 1968. Although exposure room number 4 (ER 4) is no longer in use, most experiments can be accomplished in ER 3 (see Figure 1) with the LINAC in use approximately 80 percent of one shift.

The AFRRI LINAC provides radiation researchers with a source of high-energy electrons or high-energy bremsstrahlung (X rays). Most of the experiments conducted using the LINAC are in support of the radiobiology research mission of AFRRI. Support is also given to work involving tissue sterilization as well as studies concerning electromagnetic pulse (EMP) and radiation damage to electronic semiconductor circuits and devices.

Since the LINAC has six accelerating sections that can be powered by up to four klystron microwave amplifiers, a variety of machine configurations can be used. Thus, modes A, A', and B can be used to obtain electron energies continuously variable from 10 to 54 MeV and also beam currents up to 3.25 amps.

Exposure room 3 is available to investigators along with provisions for placing and aligning most types of experiments. The typical dose rate gradient in ER 3 is approximately 2-4 megarads/pulse over a 1 cm^2 area close to the beam exit window and down to 1000 rads/minute over a 1 m^2 area at 5 meters from the exit window. The pulse repetition rate is adjustable from single pulses to 1 kHz, with the dose rate varying accordingly.

DESIGN AND OPERATION

A linear particle accelerator is a device for increasing the energy of charged particles as they pass through the accelerating structure on a single pass. Acceleration is attained by matching the velocity of the charged particle to that of the accelerating microwave. This action effects the transfer of energy from the microwaves to the particles, thus increasing their velocity and relativistic mass. The entire process is conducted in a high-vacuum (10^{-8} torr) environment.

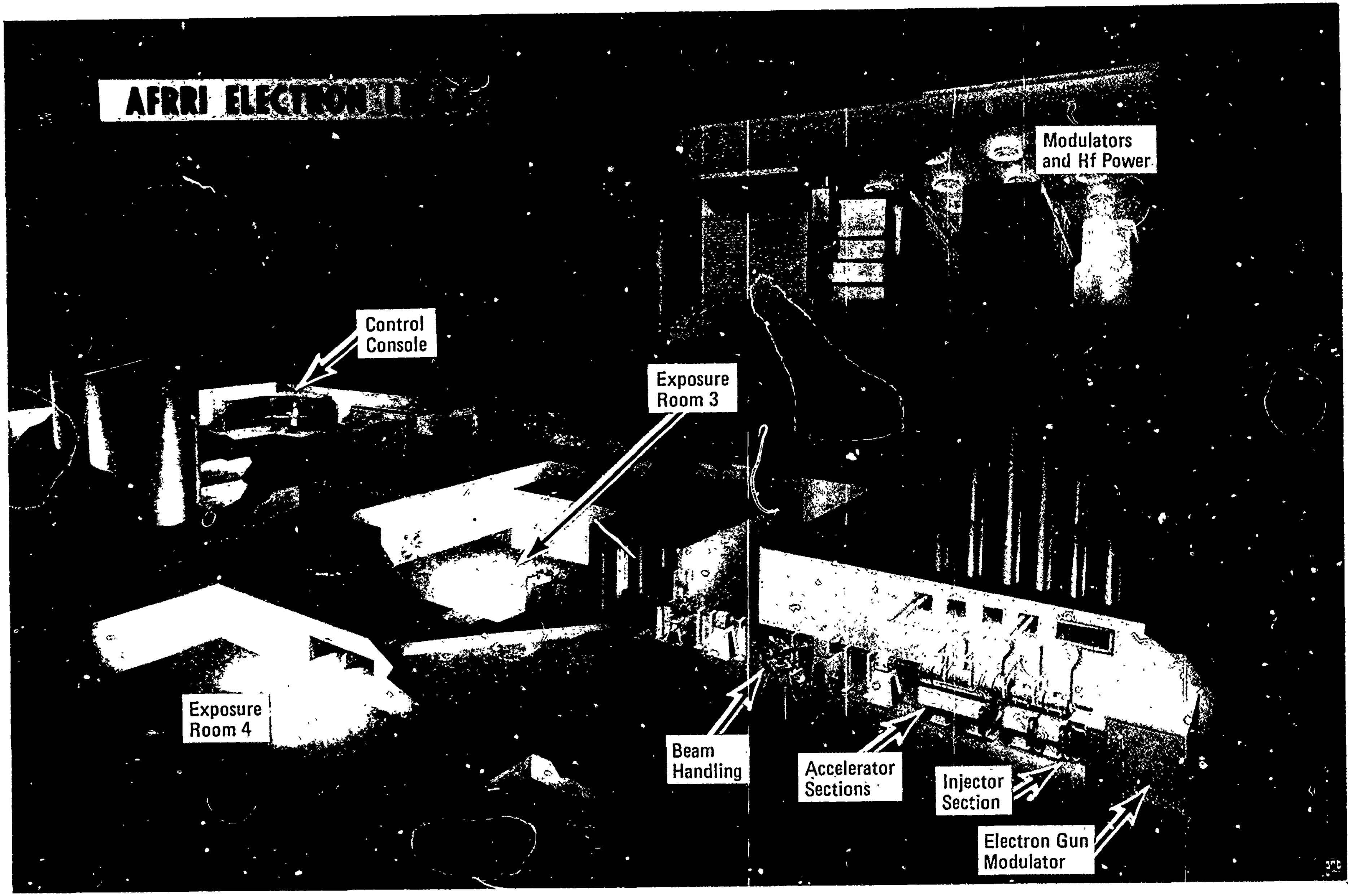

Figure 1. Varian V-7725 electron linear accelerator installed at AFRRI

In the AFRRI linear accelerator, the charged particles accelerated are electrons emitted from a 2000°C tungsten cathode in the electron gun (see Figures 2 and 3). To do this, the gun is powered in such a manner by the gun modulator and high-voltage power supplies to produce sublight electrons at 120-kV, 15-amp beam currents (see Figure 4). The beam current is in the form of pulses of electrons 4-10 microseconds in duration each, with pulse rates selective up to 1 pulse/millisecond.

The sublight-speed electron beam pulse is then shaped by focusing electromagnets, steering magnets, and collimators in the injector system. Pulse widths are continuously variable from 50 nanoseconds to 10 microseconds by use of an inflector and collimator arrangement, which electronically removes the unwanted portion of the 10-millisecond beam pulse. The beam pulse then enters a radiofrequency (RF) prebuncher, where it is compressed into small packets or bunches and then matched in phase with the 2.8-GHz microwave power in the prebuncher cavity. The electron bunches are then ready to absorb energy for acceleration to near the speed of light.

The first eight cavities of accelerating section 1A constitute the buncher. Each cavity in the buncher increases the RF phase velocity of the microwave and transfers energy to the electron beam bunches. The electron beam pulse leaves the buncher section with a velocity close to light speed ($\simeq$98.97%c). The resultant electron energy at this point is approximately 3 MeV.

Additional energy is transferred to the beam during passage through the remaining seven cavities of section 1A and through accelerator sections 1B, 2A, 2B, and in mode B (30-50 MeV operation) sections 3A and 3B. The beam pulse emerges from section 2B at an electron energy between 10 and 20 MeV in Modes A or A', and from section 3B at 30-50 MeV, depending on system adjustments.

When lower velocity electrons are compressed into tight bunches, forces within the bunch tend to push the electrons off the beam centerline of the accelerating sections. This force is countered by a rather large solenoid electromagnet surrounding the sections, which produces a 1000-gauss to 2000-gauss field. Steering coils are placed to keep the beam centered in the iris apertures. The beam-handling system, used to transport the beam after acceleration, includes quadrupole doublets, beam current monitors, and steering coils.

Quadrupole pairs are provided at a number of locations along the beamline for focusing and to permit adjustment of the electron beam spot size on the target in use. These dual electromagnetic units permit focusing of the beam along horizontal and vertical axes. Steering coils are used to center the beam in the beam pipe, which is maintained at 10^{-8} torr.

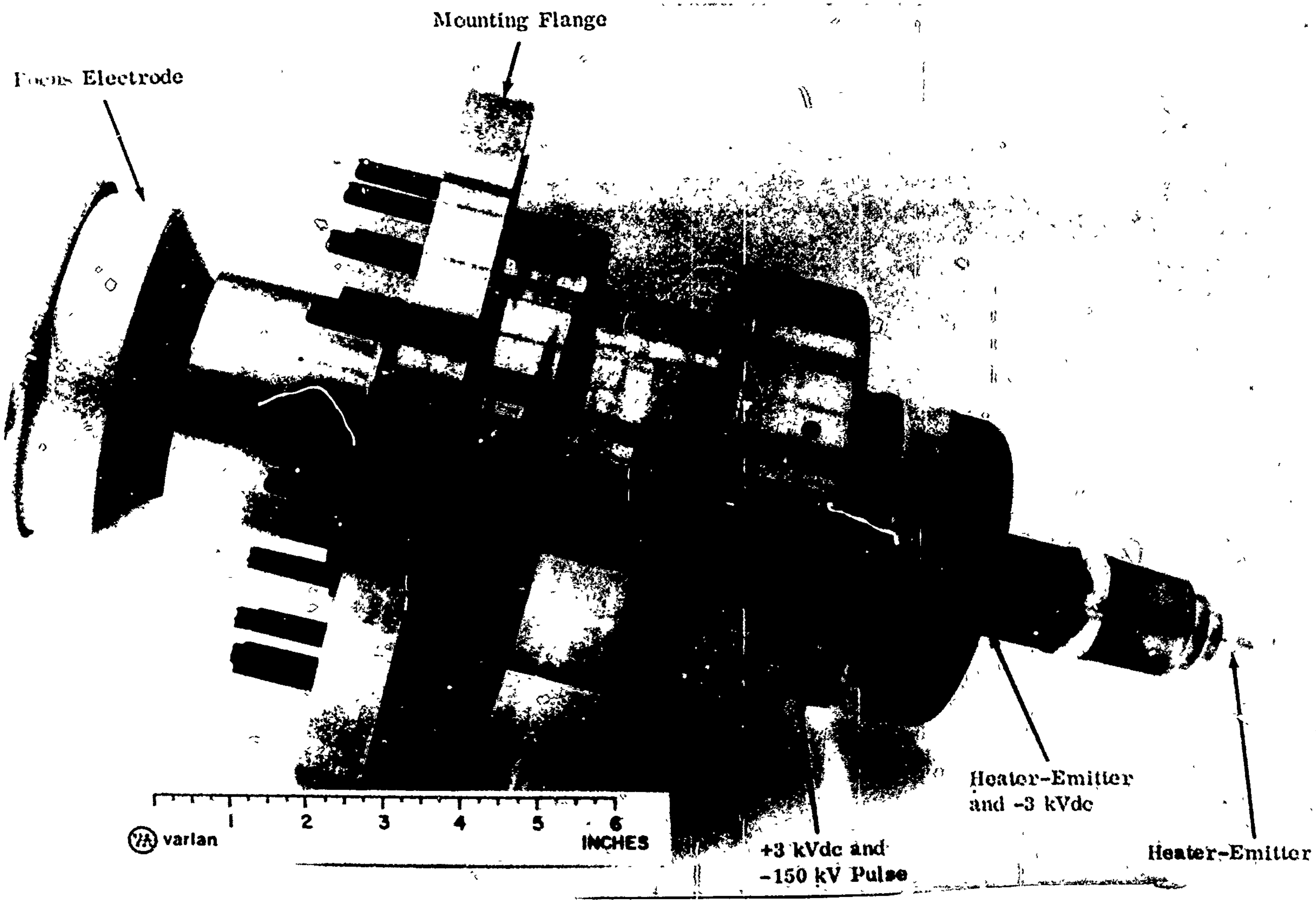

Figure 2. Mark V Model II electron gun, showing heater and high-voltage connections

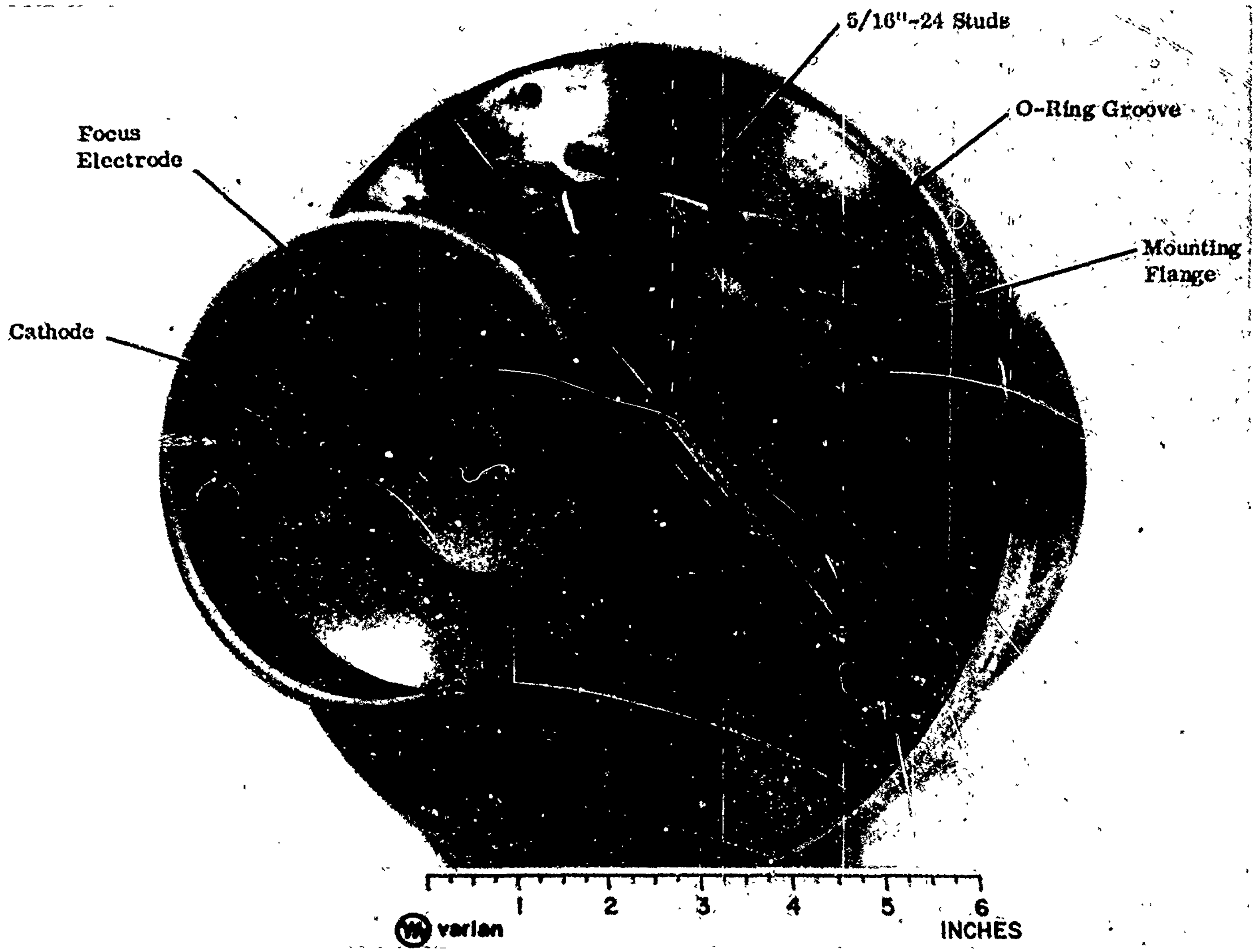

Figure 3. Mark V Model II electron gun, end view showing focus electrode and cathode

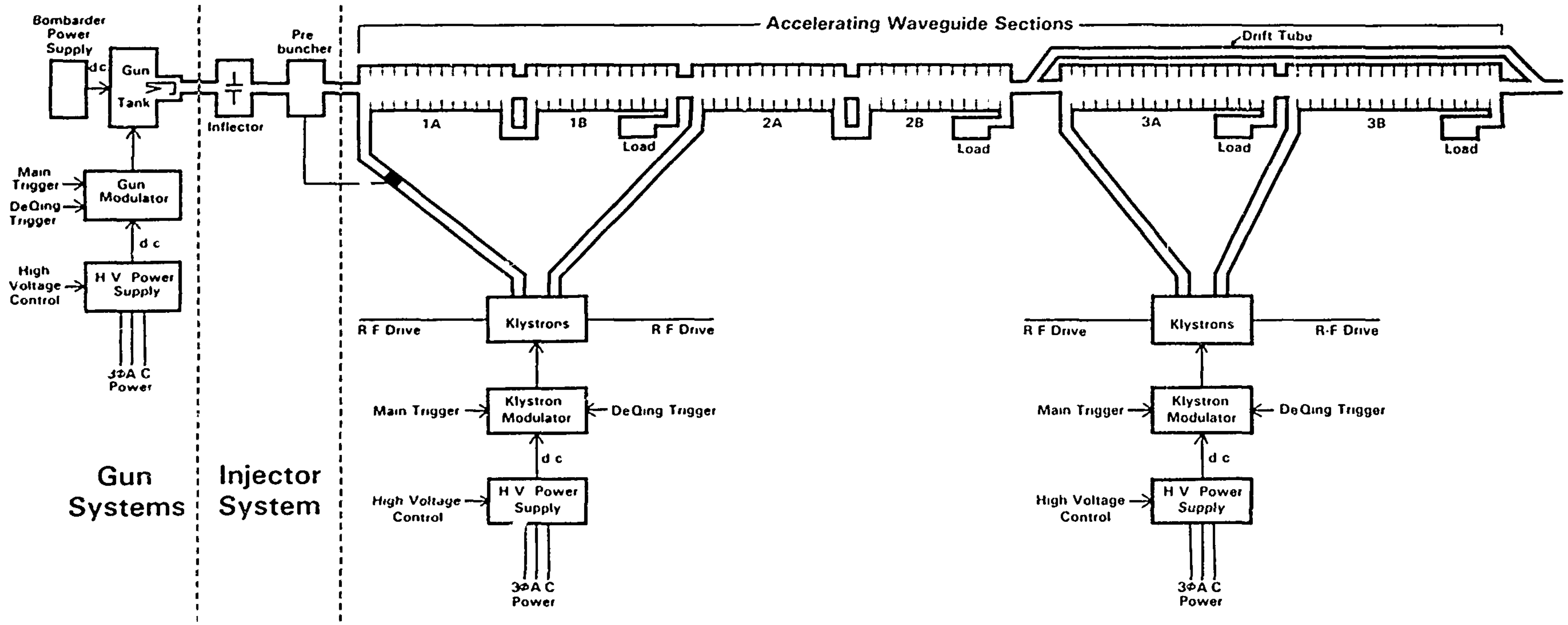

Figure 4. Linear accelerator shown in Mode B connections

The energy used to accelerate the beam is produced by four high-power klystron amplifiers, and is delivered through copper S-band waveguides to the accelerator sections. These klystron tubes amplify a preamplified continuous microwave at 2.855120 GHz to 20 megawatts peak power, or about 20 kw average output power. Two klystron modulators supply high-voltage pulsed power to the klystrons. This energy is then distributed to the accelerating sections in the proper phase, and the power level is adjusted by the operator for the desired beam characteristics.

In order to use the accelerator for a given experiment, the machine must be set for the desired energy and beam power level. This is accomplished by the operator, who first sets initial power levels on the gun modulator and on the klystron modulators. After these systems stabilize, the electron beam is transported and tuned through the injector system. The beam is then ready to enter the accelerating sections, each of which must be tuned or optimized for the desired energy by adjusting both the input microwave power level and the phase relationship with each other section. Once the beam is accelerated, it is analyzed in the 45° bending magnet to determine beam energy and energy distribution. Energy distributions are typically ± 10%. Since the LET (linear energy transfer) is nearly the same for these particles, a narrow energy distribution would only decrease the beam current. After the energy is measured, the operator then tunes the beam-handling system to place the beam in the area where the target is to be irradiated. Tuning time required to place the beam in ER 3 ready for dosimetry is approximately 1 hour. When dosimetry has determined the dose rate for the target, the accelerator is then ready for use by the investigator.

FACILITY CAPABILITY

Since the deliverable dose rates are quite variable and high (up to 2-4 megarads/pulse), the AFRRI LINAC is a powerful and flexible radiation source that has a wide spectrum of potential research uses. Applications include, for example, studies of radiation effects at high dose rates relating to radiobiology, radiochemistry, materials, and components, and the sterilization of tissue and equipment; bioburden reductions of 10^9 are possible. If a target requires a greater penetration depth than that of high-energy electrons, the beam can be converted to bremsstrahlung (X ray) and used in those cases where the mean free path or range of the electrons is too low. Three-MeV photons are the average energy for bremsstrahlung when an 18-MeV electron beam is incident on the converter.

In addition to the bremsstrahlung converter, a water-cooled beam scatterer is used in ER 3 to provide a more uniform beam cross section to irradiate large targets. ER 3, which is 6 meters X 5 meters X 5 meters, is equipped with a laser alignment system to position targets in the center of the beam.

When remote controls and sensor instrumentation are required to support the experiment package but are not to be used in the radiation environment of ER 3, the LINAC readout room can be used. It has sufficient equipment rack space for support of most experiments.

For more information about the AFRRI LINAC facility or to inquire about possible use, contact either the Chief, Radiation Sources Division, at (301) 295-1048 or the LINAC facility manager at (301) 295-1288.